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Poisoned baits drive record golden eagle mortality in northern Greece: A call for urgent conservation actions

Lavrentis Sidiropoulos [a], D. Philip Whitfield [b], Anastasios Bounas [c], Elzbieta Kret [d], Elisabeth Navarrete [e], Panagiotis Vafeidis [f], Dimitrios Doukas [g], Panagiota Michalopoulou [h], Sylvia Zakkak [i], Vassiliki Kati [a,*]

[a] *Laboratory of Biodiversity Conservation, Dept of Biological Applications and Technology, University of Ioannina, Ioannina University Campus, 45100 Ioannina, Greece*
[b] *Natural Research Ltd., Brathens Business Park, Hill of Brathens, Banchory, Aberdeenshire, 4BY, Scotland, UK*
[c] *Laboratory of Molecular Ecology and Conservation Genetics, Dept of Biological Applications and Technology, University of Ioannina, Ioannina University Campus, 45100 Ioannina, Greece*
[d] *Society for the Protection of Biodiversity of Thrace, 68400, Dadia, Evros, Greece*
[e] *Hellenic Ornithological Society / BirdLife Greece, Agiou Konstantinou 52 st., 10437, Athens, Greece*
[f] *Stavroupoli Forestry Service 67062, Stavroupoli, Xanthi, Greece*
[g] *Laboratory of Animal Pathology & Veterinary Forensics, Faculty of Veterinary Science, University of Thessaly, 224 Trikalon st., Karditsa 43100, Greece*
[h] *Laboratory of Forensic Toxicology, Ministry of Rural Development and Food, Neapoleos st. 25, 15341, Ag. Paraskevi, Athens, Greece*
[i] *Natural Environment and Climate Change Agency, Mesogeion Ave. 207, 11525 Athens, Greece*

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ABSTRACT

Despite an overall recovery of European large raptor populations, the golden eagle (*Aquila chrysaetos*) population in Greece is Endangered. Poisoning from baits set illegally for carnivore control is known as an important mortality factor, impacting a wider avian scavenger assemblage in our study area. We analysed golden eagle mortality data from northern Greece for the last 35 years, including the fates of 29 satellite-tagged individuals from the last decade. Poisoning accounted for 65 % of the overall mortality, the highest percentage recorded globally for any eagle population. Known fate survival models from telemetry data revealed 0.78 and 0.85 annual survival rates for immature and adults, respectively (the lowest reported in telemetry studies), improving markedly when censored for poisoning mortality. Poisoning occurred disproportionally close to protected areas, more often in areas with high carnivore livestock depredation and almost exclusively in winter when eagles were more likely to scavenge. Golden eagles were usually poisoned by directly feeding on carcasses and offal baits laced predominantly with illegal toxic substances (e.g. carbofuran and methomyl). Electrocution was the second cause of mortality, and collision with turbines was also recorded. The main conservation implication of our findings is that urgent policy changes are required to reverse the population's decline, mainly against the illegal use of poisoned baits and across prevention, legislative and enforcement levels. We propose specific measures towards this direction, such as improving livestock husbandry, further capacity building for wildlife crime investigation and reforms in relevant legislation.

1. Introduction

Long-term conservation efforts have improved the conservation status of most European raptor populations (BirdLife International, 2017), but regional trends remain unfavourable for many species, particularly for obligate and facultative scavengers (Angelov, 2024; Velevski et al., 2015; Xirouchakis, 2019). Understanding the causes of avian population declines provides the fundamental knowledge base for reversing them (Green, 2002; Loss et al., 2015). For large raptors, territorial adult mortality is a key demographic constraint (Penteriani et al., 2005; Whitfield et al., 2006). Mortality during the transient dispersal period is usually the highest (Fielding et al., 2023; Newton

* Corresponding author at: University of Ioannina, Department of Biological Applications & Technology, Ioannina University Campus, Ioannina 45500, Greece.
E-mail addresses: l.sidiropoulos@uoi.gr (L. Sidiropoulos), phil.whitfield@natural-research.org (D.P. Whitfield), abounas@uoi.gr (A. Bounas), e.kret@spbt.gr (E. Kret), enavarrete@ornithologiki.gr (E. Navarrete), pvafeidis@eedpmt.ypen.gr (P. Vafeidis), ddoukas@vet.uth.gr (D. Doukas), pmichalopoulou@minagric.gr (P. Michalopoulou), s.zakkak@necca.gov.gr (S. Zakkak), vkati@uoi.gr (V. Kati).

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et al., 2016) and can also impact population persistence (Penteriani et al., 2008; Penteriani et al., 2005).

Human induced mortality causes reported for European raptors are poisoning (Buij et al., 2025), electrocution and collision with energy infrastructure (Dahl et al., 2013; Hernández-Matías et al., 2015) and especially in S. Europe, shooting (Pedrini and Sergio, 2001; Xirouchakis, 2001). Mortality causes can be identified through necropsies and clinical examinations of recovered birds (McIntyre, 2012), analysis of data collected in recovery sites (Lazarova et al., 2020), interviews with authorities and land users (Pedrini and Sergio, 2001; Xirouchakis, 2001), and wildlife hospital admission records (Müller et al., 2007).

Raptors are among the most threatened avian taxa in Greece (Vavylis et al., 2021). The golden eagle is an iconic species useful in public awareness. It is symbolic for nature conservation, as a top predator an indicator of ecosystems integrity and carries a significant cultural value in Greece (Stara et al., 2016). It has been protected since 1983 but is still endangered (EN) (Bounas and Sidiropoulos, 2024) with most mainland populations declining (Sidiropoulos et al., 2024b). Historically, the species suffered widespread persecution, primarily through shooting (Hallmann, 1985; Xirouchakis, 2001). Poisoning now appears to be the top threat (Sidiropoulos et al., 2024b), despite bans on poisoned baits in Greece 1993. This illegal practice, commonly used for carnivore control, frequently results in raptor fatalities as non-targeted victims (Ntemiri et al., 2018). Persecution in remote areas is challenging to document and prosecute, though land use often reveals underlying drivers (Newton, 2021; Whitfield et al., 2003). Satellite telemetry offers unbiased mortality data (Crandall et al., 2019; Whitfield and Fielding, 2017) and can uncover case details otherwise inaccessible (Csermak Jr et al., 2023; Peshev et al., 2022). Identifying and publicising illegal persecution cases supports conservation, enhances law enforcement and guides targeted awareness campaigns (Giraldo-Amaya et al., 2021).

Greek law follows EU regulations banning poisoned baits, e.g. Annex VI, EC 92/43 (EC, 1992). The national legislative framework on domestic animal welfare has been recently expanded to protect wildlife, including anti-poisoning provisions for protected species, such as the golden eagle (article 188 of law 5037) (Government Gazette of the Hellenic Republic, 2023). Although the intentional killing of protected species has been upgraded to a felony, in itself a positive step incurring high penalties for direct persecution such as shooting, this direct "transfer" of legislation originally enacted for domestic animals might prove challenging in its application. Poisoning non-protected species, such as red foxes (*V. vulpes*) or wolves (*Canis lupus*) (above the 39^{o} N parallel), is considered a misdemeanour with trivial consequences for perpetrators. This 'intention' ambiguity might be used to alleviate penalties as raptors are not directly targeted. To our knowledge, no successful prosecution has ever been achieved in Greece for poisoning protected wildlife.

This study updates the pattern of mortality causes for golden eagles in northern Greece (Sidiropoulos et al., 2024b), focusing on poisoning, using three decades of data (1991–2025) to address critical conservation concerns. We aimed to (i) rank mortality causes for golden eagles in northern Greece in terms of their severity, (ii) analyse poisoning practices, (iii) investigate seasonal patterns of poisoning, hypothesising higher incidences in winter due to increased scavenging, (iv) assess the spatial distribution of poisoning relative to protected areas, (v) explore links between poisoning and livestock depredation, (vi) evaluate golden eagle survival rates with a focus on poisoning, and (vii) assess poisoning impacts on other wildlife. We also reviewed global literature on mortality causes for seven eagle species and golden eagle survival rates, interpreting findings within a conservation policy framework.

2. Methods

2.1. Study area

The study area was northern Greece (Macedonia and Thrace), covering 42,801 km^2 (Fig. 1). The climate was Mediterranean – continental Mediterranean and the terrain hilly, with an average altitude of 486 m (0 to 2917 m). Predominant covers were farmland (43.1 %), woodland (27.9 %), and scrub or open areas (23 %), supporting activities such as agriculture, livestock rearing, and forestry. The remaining 6 % consisted of wetlands, waterbodies, and artificial surfaces (European Union / Copernicus Land Monitoring Service, 2018). Hunting was permitted in all its extent except in Wildlife Refuges (10.9 %) and zones near settlements and other infrastructures. The Natura 2000 network of protected areas covered 33.1 % of the study area, and an additional 5.6 % was covered by non-overlapping Wildlife Refuges.

2.2. Data collection

We compiled two datasets for known mortality cases of golden eagles in northern Greece, including other poisoned wildlife species near the incidents (up to 4 km distance). The first dataset (1991–2023) included 35 cases and combined data from Governmental (n = 4) and Non-Governmental Organizations (n = 15), wildlife hospital admissions (n = 8) and interviews with land users (n = 8) (Methods in Appendix A1, dataset details in Table B1). The second dataset included 14 cases from telemetry data, (n = 29 satellite-tagged golden eagles) and three untagged individuals recovered alongside them (2015–2025) (Methods in Appendix A2, dataset details in Tables B1 and B2). We considered only cases of birds that were fully fledged and developed flight capabilities (i.e., over one month post-fledging).

We distinguished six causes of death (hereafter COD): poisoning, shooting, electrocution, collisions with wind turbines, accidents, and unknown. We determined COD by combining evidence from (a) necropsies and clinical examinations of living birds, (b) field autopsies, (c) toxicological analyses, and (d) interviews conducted in the field (Laboratory and detection Methods in Appendix A3).

2.3. Data analysis

Data were analysed in R using the "terra" package and visualised in QGIS (Hijmans, 2024; QGIS Development Team, 2021; R-Core_Team, 2023). To evaluate the severity of the mortality causes in our population, we performed chi-square tests to check for differences with a random (equal) expected distribution among different CODs. Looking into poisoning practices and impacts, we calculated the frequency of bait types and substances used (toxic substances in Table C1). For spatial analysis, we considered only the incidents with accurate localities available (n = 21). To explore the seasonal patterns of poisoning incidents, we considered only the incidents with known times of fatalities (n = 32). We divided the year into two periods: winter (October–March) and summer (April – September), following the brumation period of tortoises (Stojadinović et al., 2017), the main prey of our study population (Sidiropoulos et al., 2022). We then used a chi-square test with expected values of an equal incident distribution between the two seasons to test for statistical differences.

To explore the spatial patterns of mortality cases in relation to protected areas (Fig. 1), we used a golden eagle habitat preference model for dispersing eagles (Fielding et al., 2019) and territorial adults (Fielding et al., 2024), and adapted to our study area (Sidiropoulos et al., 2024a). We extracted highly suitable areas as those with a suitability class $\geq$ 6 on a scale of 10 discrete classes of the model (10 is the highest suitability class). We computed the ratio of highly suitable areas within protected areas over the overall high suitability area (ratio 1). We then computed the ratio of poisoning incidents falling at a distance $<$ 1 km from the highly suitable areas of the protected areas over the total number of incidents (ratio 2). We used the two ratios to investigate whether eagle poisoning occurred more in and around protected areas through a proportion test (Crawley, 2013).

To explore the relationship of poisoning with human - large carnivore conflict intensity, we obtained data on the number of depredation

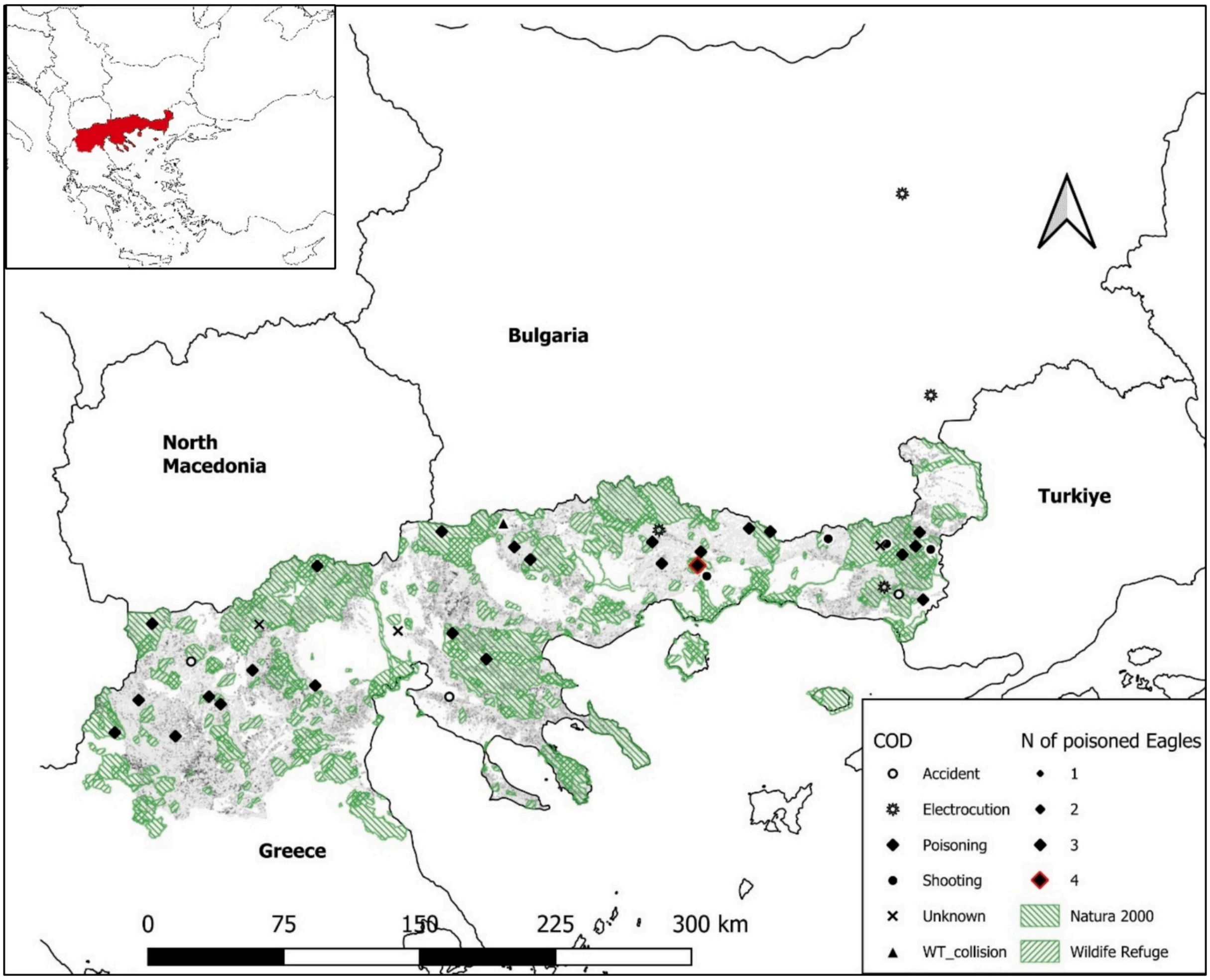

Fig. 1. Recorded golden eagle fatalities by cause of death in Northern Greece (Macedonia – Thrace administrative division) across protected areas. Background indicates habitat suitability, noting with darker colours areas of higher suitability (modified by Sidiropoulos et al., 2024a). Inset shows study area location in SE Europe.

incidents of wolf and bear and the related number of livestock animals killed at the municipality level for the period 2012–2021, from the Hellenic Agricultural Insurances Organization (Figs. D1, D2). For each municipality, we computed the carnivore (bear and wolf) attack rate as the number of attacks per 100 km^2 and then extracted the average rate in a 5 km buffer around the 21 known localities of poisoning incidents. This buffer was applied to accommodate both the intrinsic dataset spatial coarseness and the extensive large carnivore ranging behaviour (Kanellopoulos et al., 2006; Mancinelli et al., 2018). We then calculated the respective depredation rate in 10,000 sets of 21 random 5 km buffers in the whole study area. We compared the means of depredation rates between the two datasets (21 incidents and 10,000 random point sets), and we used the position of the actual mean in the distribution of the random dataset as a test statistic (Gotelli and Ellison, 2004).

To estimate golden eagle survival rates, we specified quarterly intervals, considering separately 22 juvenile birds (tagged as fledglings) and seven birds of breeding age ($\geq$ 4th calendar year, hereafter c. y.). Juveniles were thus entered at the beginning of the study (at age 0.25, second yearly quarter) and all territorial birds at a separate interval at the beginning of the first quarter of the fourth year. We used the known fate model with the logit-link function in the program MARK (Pollock et al., 1989; White and Burnham, 1999) implemented in the “RMark” package (Laake, 2022). We fitted age and season models to derive age and season-specific survival rates. Model performance was evaluated using Akaike's information Criterion corrected for small sample sizes (AICc). We reran the final model after censoring poisoning mortality to assess the effects of poisoning on eagle survival (Appendix E, Table E1).

2.4. Literature review

We performed a literature review for all eagles ‘mortality causes worldwide (terms “eagle” and “poisoning”/ “mortality” in Scopus database), in addition to specific monographs on the golden eagle (Bautista and Ellis, 2024; Watson, 2010). We also conducted a literature review for the survival rates of the golden eagle populations worldwide (terms “golden eagle” and “survival” in Scopus database).

3. Results

3.1. Mortality causes

Since 1991, we collected 52 cases of golden eagle recoveries in 42 incidents. We were able to assign COD in 49 of them (Table B1, B3). Mortality was almost entirely human-induced (90 %) and poisoning was by far the main cause, accounting for 65 % of all fatalities, followed by shooting (12 %) and electrocution (10 %) (Table B3). In the telemetry dataset only, poisoning accounted for 10 out of 14 recovered tags from 29 deployments. The COD distribution was significantly different from random in both datasets treated (χ^2 = 49.9 for the various-sources dataset and χ^2 = 46.2 for the telemetry dataset df = 5, $P < 0.0001$).

3.2. Poisoning practices and impacts on other wildlife

Four substances were detected in baits, with carbofuran and then methomyl being the most frequently used (Table C1). Where known (n = 27 cases), most golden eagles (74 %) died after direct ingestion of baits, while the rest (26 %) suffered secondary poisoning, namely by consuming other carnivores. Perpetrators prepared entire carcasses (n = 9) and in a few cases the offal piles with poison (n = 3). We excluded incidences without available data (interview data, other cases before 2000, the most recent incident of January 2025 where tests are pending- see Fig. D2). Toxicological tests were run in 15 incidents covering 21 cases (six in the first and nine in the second dataset. In five incidents / cases, where sole eagles were recovered near carcasses, tests could not detect the toxic substance (three in the first and two in the second dataset). In seven incidents, more than one eagle was recovered (range 1–3 additional birds) and in six incidents other raptors and carnivores were involved.

In total, 45 raptors and 41 carnivores were recovered in the vicinity of baits that killed golden eagles, including other protected raptors such as vultures, harriers and kites, as well as wolves and foxes, being the likely target species (inventory of other wildlife species affected presented in Table C1).

3.3. Poisoning seasonality

Of the 32 cases of a known period of poisoning, 94 % occurred in winter (October–March), especially in January and February (58 % of cases) (Table B1). This difference was significantly higher than summer poisoning ($\chi^2 = 14.2$ for the various-source dataset, $\chi^2 = 10.3$ for the telemetry dataset, df = 1, $P < 0.002$).

3.4. Poisoning in protected areas

The extent of highly suitable habitat in the study area was 19,744 km^2, and almost half (45 %: 8907 km^2) fell within protected areas. Most poisoning incidents (71 %) were within 1 km of protected areas with highly suitable habitat (median distance 370 m) (Fig. 1). The proportion test showed that protected areas had not a buffering role against poisoning, as that golden eagle poisoning occurred significantly more near protected areas proportionally to the size of highly suitable habitat ($\chi^2 = 4.85$, df = 1, $P < 0.03$).

3.5. Poisoning and livestock depredation

The rate of large carnivores' attacks on livestock was two times higher in the area of poisoning incidents 49.11 (± 50.9) attacks per 100 km^2 for the period 2012–2021 compared to random set means 19.47 (± 5.5) attacks per 100 km^2 and was within the upper 0.1 % percentile (47.4) of random sets distribution (n = 10,000, Fig. D1).

3.6. Poisoning impact on Golden eagle survival rates

The model showed that the yearly survival estimate was 0.85 in adults (≥ 4 years old) and increased to 0.96 in the censored model excluding poisoning. The same pattern was observed in immatures (1st – 3rd calendar year) showing lower survival rates, which increased from 0.78 to 0.91 respectively (Table 1). Season improved model performance (ΔAICc = 1.41) and winter survival rates were substantially lower for both age classes, showing larger confidence intervals (Table 1, Appendix E).

3.7. Review of eagle mortality causes and Golden eagle survival rates

The poisoning mortality of golden eagles in the study area (65 % n = 52) was the highest recorded globally, with rates of other studies on the species ranging from 0 to 61.4 % across 22 studies (average rate of 14.8 % (±13.8 %)). The rates ranged from 2.9 to 38 % (average 18.6 % (±10.2 %)) for another six eagle species across 15 studies (Table F1).

The survival rate of the adult golden eagles in the study area (0.85) was among the lowest across 11 studies reviewed and the lowest among telemetry studies (Table 1, Table F2). The respective rate for 2nd – 3rd cy immatures (0.73) was also the lowest reported (three studies reviewed) as well as for the first three years of life (0.78) (two studies reviewed). However, the survival rate was the highest for the first year of life (0.88) (three studies reviewed) (Table F2).

4. Discussion

4.1. Mortality causes

Mortality was almost entirely human-induced, as expected for a species with no natural predators once fledged (Watson, 2010), and a declining population where territorial disputes should be rare, unlike saturated populations (Haller, 1996). The 10 poisoned satellite tagged individuals in our study represent an alarming one-third of all deployed tags (n = 29). Our results corroborate earlier evidence of severe poisoning mortality in the studied population (Sidiropoulos et al., 2024b) and highlight the magnitude of the illegal poisoned bait use in the Greek countryside (Ntemiri et al., 2018). Poisoned baits have substantially affected Balkan populations of avian scavengers of conservation concern (Velevski et al., 2015; Xirouchakis, 2019), as is evident also of our findings of two griffon (*Gyps fulvus*) and nine cinereous vultures (*Aegypius monachus*) among the victims of our poisoning cases. Their impact on golden eagle populations, however, has so far been overlooked compared to vultures and carnivores, where most conservation efforts have focused (Chapron et al., 2014; Oppel et al., 2016; Skartsi et al., 2010). Our study showed that the population suffers from the highest poisoning mortality recorded for any eagle population worldwide.

Although shooting was the second in rank cause of mortality, it seems to have diminished, being absent from the telemetry dataset, with the last incident recorded 20 years ago. On the other hand, electrocution still seems to be an important mortality cause, known to substantially affect bird populations in the Balkans, including raptors of conservation concern (Demerdzhiev et al., 2014; Demerdzhiev et al., 2009). Moreover, wind farm development in Greece is expanding into mountainous and natural areas (Kati et al., 2023; Kati et al., 2021) increasingly overlapping golden eagle habitats (Sidiropoulos et al., 2024b). Besides the scope for increasingly extensive functional habitat loss (Fielding et al., 2021), turbine collision mortality should also be expected to rise

Table 1
Estimated survival rates for adult and immature golden eagles (95 % Confidence Intervals), with poisoning censored and per season. Numbers in the age group column are summarized estimates from available studies (median, range, n = number of studies reviewed).

Age group		Survival rate −/+ 95 % CI		
		Overall	Winter	Summer
Adult; median = 0.895 (0.76–0.975, n = 10)		0.85 (0.66–0.94)	0.78 (0.54–0.92)	0.97 (0.75–1)
	Censored	0.96 (0.76–0.99)	0.96 (0.74–1)	0.96 (0.71–1)
Immature (0.8–0.89, n = 2)		0.78 (0.64–0.87)	0.66 (0.45–0.82)	0.93 (0.71–0.95)
	Censored	0.91 (0.78–0.96)	0.92 (0.70–0.98)	0.90 (0.72–0.97)

in the future, as predicted for other species (Bounas et al., 2025).

4.2. Poisoning practices

Our results showed that carbofuran was the most frequently active substance used in baits *(29 % of cases, $n = 35$)*, consistent with a European-wide study on raptor poisoning (Buij et al., 2025). Although banned EU-wide in 2008, 90 % of incidents ($n = 10$) occurred afterwards, suggesting the existence of non-sequestered stocks or illegal imports from neighbouring countries (Kitowski et al., 2021; Ntemiri et al., 2018). The inability to determine substances in four cases was likely due to advanced decomposition, concentrations below the detection limit or the lack of analytical methods for all active substance groups.

4.3. Seasonal patterns

We found that eagles were poisoned almost exclusively in winter (94 %, $n = 32$), although the use of poison baits is a year-round practice (Ntemiri et al., 2018). While poisoning cases of obligate scavenger raptors in Europe are reported to peak in March–April (Buij et al., 2025), in our case, they peaked in January–February. We attribute this pattern to the winter diet breadth expansion due to the absence of the main prey (tortoises), leading to increased carrion consumption (Sidiropoulos et al., 2022), greater vulnerability to poisoning, and lower survival estimates.

4.4. Poisoning in protected areas

In agreement with a study in North-Western Spain (Mateo-Tomás et al., 2012), our findings showed that poisoning incidents were recorded disproportionately close to protected areas, underlining the poor implementation of the protected areas network (European Commission, 2017) and its inefficiency in curtailing illegal activities (Kati et al., 2015).

4.5. Drivers of poisoning

The prevailing reason for bait use in Greece is disputes between land users and retaliation acts, followed by livestock protection or game protection against predators, involving mainly livestock farmers and hunters (Ntemiri et al., 2018). We showed that golden eagles were more likely to be poisoned in areas with higher livestock depredation, underscoring the bait use by livestock farmers for retaliative killing of large carnivores and livestock capital protection (Mateo-Tomás et al., 2012). Furthermore, hunters have relative incentives to target smaller carnivores and wolves, viewed as threats to game populations and the latter, also to valuable hunting dogs which can be vulnerable to wolf depredation in our study area (Iliopoulos et al., 2021). Clearer patterns might emerge if livestock depredation rates and land use are combined with territory occupancy and indirect mortality assessments through monitoring the ages of pairs across the study area (Ferrer et al., 2003; Hernandez-Matias et al., 2011).

4.6. Golden eagle survival rates

Our results on golden eagle survival rates were among the lowest reported for both age classes of adults and immatures, apart from juveniles. All 10 adult survival estimates reviewed in Tikkanen et al. (2024); table F2) were higher than our estimate of 0.84 (range of 10 studies 0.86–0.975). Only some indirect estimation methods, other than telemetry, showed lower rates for this most crucial population parameter (Whitfield et al., 2006). For the entire immature period (1-3rd c.y.), the two available estimates for non-territorial segments of resident populations (Hunt et al., 2017; Whitfield and Fielding, 2017) were both higher than our 0.78 annual rate (0.8–0.88 respectively, although the Scottish population that is deliberately persecuted was censored for a high segment of probable human-induced mortality). On the other hand, juveniles, after fledging, remained in their territory until one year old, with parental provisioning. Their high-risk period (October–December) was shorter than that of wider-ranging second- and third-year immatures, reducing bait exposure. Considering survival rates for immatures (1–3 c.y.) and adults, and the population's estimated productivity of 0.53 chicks/pair/year (Sidiropoulos et al., 2024b), only the upper confidence intervals (0.94 for adults and 0.89 for immatures) were within healthy population values (Whitfield et al., 2004). In the absence of poisoning, annual survival rates improved markedly for both age classes and the seasonal mortality pattern was also corroborated, as lower winter estimates converged with summer.

4.7. Methodological insights

We conducted a comprehensive study focusing on poisoning as the main mortality cause for our studied golden eagle population, based on available data and inherent limitations. First, the mortality dataset was derived from various sources and included 23 % ($n = 52$) of data collected through interviews that were less reliable than other methods. However, these incidents were reported in known golden eagle territories where no other eagle species was likely present, and telemetry evidence confirmed twice poisoning incidents close to cases reported by interviews (Table B1, Fig. D2). In any case, even excluding interview data from the analysis, poisoning mortality still exceeds 60 % ($n = 48$) in the population. Second, the national livestock depredation database used was available at a coarse municipality scale and might not be complete, and < 10 % ($n = 23$) of poisoning cases missed exact georeference. We attempted to overcome spatial uncertainty by applying a buffer around incidents and standardizing by area, to reveal the relationship between incident frequency and livestock depredation intensity. Third, a more robust survival model could be built if time-series data were available for many individuals. The current model produced large confidence intervals in survival estimates due to the nature of telemetry data used (multiple cohorts of few individuals, territorial birds captured in different winters) but provided a first indication of the substantial negative impact of poisoning on the population's long-term survival. Additionally, we did not examine the poisoning mortality trend for the last thirty years since the trend could reflect either genuine temporal trends (Bautista, 2024) or be confounded by non-reported incidents due to the absence of systematic long-term monitoring of golden eagle mortality. Finally, we did not have the possibility to test for lead poisoning, a major mortality factor elsewhere (Krone, 2018). Although the evidence we collected (field data, necropsies) does not point to any of our cases being directly attributable to lead, further investigation should take account of this possibility, especially as effects of lead poisoning might be masked by other apparent conditions such as unexplained trauma, otherwise avoidable in healthy birds.

Despite all the above limitations, the convergence of several lines of evidence (multiple datasets, spatial patterns, known fate survival model) clearly points to an alarming situation for our studied population, attributable to high poisoning mortality during winter. Finally, the present study is another example where satellite telemetry has proven invaluable for detecting persecution and other threats (Whitfield and Fielding, 2017; Bautista et al., 2024; Berny et al., 2015). It should be expanded in geographical coverage and intensified for both dispersing and territorial individuals, the latter especially in areas of high human–carnivore conflict.

4.8. Conservation implications for Greek policy

We believe that an urgent combination of measures at the legislative, enforcement and prevention levels is needed, and we provide a list of detailed potential measures in Appendix E. First, dedicated wildlife crime legislation is required to clarify and streamline legal processes and alleviate jurisdiction conflicts. Specialised wildlife crime investigation is needed, adopting Standard Operating Procedures (Valverde et al., 2022) and sophisticated forensic techniques, such as those established by the Balkan DETOX LIFE project (LIFE19 GIE/NL/001016), whose capacity building should be expanded and include the judiciary. Standardization should apply in on-site investigation procedures. and necropsies. There is an urgent need for investment in the capacity of toxicological analyses to obtain immediate results. Poisoning, or suspected poisoning incidents, must be prioritised in the investigation, and strict penalties must be applied in successful prosecutions.

At the same time, preventive policies against the motives of poisoned baits use, should focus on the improvement in compensation of livestock depredation, support for novel and traditional ecological knowledge applications in livestock husbandry (Durá-Alemañ et al., 2024; Iliopoulos et al., 2019; Petridou et al., 2023) and the engagement of the hunting community. Specifically for the golden eagle, result based Agri-environment measures (rewarding for golden eagle pair presence) can be implemented in key breeding and dispersal areas (Herzon, 2022), in combination with supplementary feeding at least during the winter months (López-Peinado et al., 2023). Finally, besides appropriate siting of potentially dangerous infrastructure (Murgatroyd et al., 2021; Vasilakis et al., 2016), retrofitting and other preventive measures, and environmental liability in case of negligence should be introduced (Appendix E, table E1).

4.9. Conclusion

This study highlights how different types of data can be used to identify crucial threats for species of conservation concern where quantitative analyses are lacking and wildlife crime interventions are urgently needed. Our results reveal that unless golden eagle poisoning is immediately addressed with a combination of engagement of land users, preventive policies and law enforcement, the golden eagle population in Northern Greece is likely to collapse like other large eagles and vultures in the country (Handrinos and Akriotis, 1997). This poisoning impact has resulted in some of the lowest survival rates and the highest poisoning mortality globally. This extreme for a facultative scavenger predicament clearly indicates the gravity of the illegal poisoned bait use in the Greek countryside, impacting several species of conservation concern such as threatened cinereous and griffon Vultures and requiring an urgent, immense statutory and enforcement investment.

CRediT authorship contribution statement

Lavrentis Sidiropoulos: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **D. Philip Whitfield:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization. **Anastasios Bounas:** Writing – review & editing, Writing – original draft, Formal analysis. **Elzbieta Kret:** Writing – review & editing, Investigation. **Elisabeth Navarrete:** Writing – review & editing, Investigation, Data curation. **Panagiotis Vafeidis:** Writing – review & editing, Writing – original draft, Investigation. **Dimitrios Doukas:** Writing – review & editing, Writing – original draft, Investigation. **Panagiota Michalopoulou:** Writing – review & editing, Writing – original draft, Investigation. **Sylvia Zakkak:** Writing – review & editing, Investigation. **Vassiliki Kati:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology.

Author's statement

We herein declare that: (a) The work is all original research carried out by the authors, (b) All authors agree with the contents of the manuscript and its submission to the journal, (c) No part of the research has been published in any form elsewhere, (d) The manuscript is not being considered for publication elsewhere while it is being considered for publication in this journal, (e) The paper in any form has not been previously submitted to Biological Conservation, (f) Any research in the paper not carried out by the authors is fully acknowledged in the manuscript, (g) All sources of funding are acknowledged in the manuscript, and no direct financial benefits result from publication, (h) All appropriate ethics and other approvals were obtained for the research.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the corresponding author used ChatGPT4 to improve linguistically some parts of the MS. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the published article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2025.111223.

Data availability

Data are presented in the Appendix. Incident localities are not publicly made available, as sensitive data that are part of ongoing prosecution process by competent authorities.

References

Angelov, I.D., 2024. Exceptionally low proportion of adult pairs and male-skewed adult sex ratio in a declining population of the Golden eagle Aquila chrysaetos (L., 1758) (Accipitriformes: Accipitridae). Acta Zool. Bulg. 76, 241–248.

Bautista, J., 2024. The Golden eagle in the Iberian Peninsula (Spain and Portugal). In: Bautista, J., Ellis, D..H. (Eds.), The Golden Eagle around the World. Hancock House Publishers, Blaine, WA, US and Surrey, BC, Canada, pp. 182–219.

Bautista, J., Ellis, D..H. (Eds.), 2024. The Golden Eagle around the World. Hancock House Publishers, Blaine, WA, US and Surrey, BC, Canada.

Bautista, J., Gómez, G.J., Otero, M., Garrido, J.R., 2024. Golden eagles in southern Spain recolonize human-dominated landscapes (1998-2021). In: Bautista, J., Ellis, D..H. (Eds.), The Golden Eagle around the World. Hancock House Publishers, Blaine, WA, US and Surrey, BC, Canada, pp. 220–253.

Berny, P., Vilagines, L., Cugnasse, J.-M., Mastain, O., Chollet, J.-Y., Joncour, G., Razin, M., 2015. VIGILANCE POISON: illegal poisoning and lead intoxication are the main factors affecting avian scavenger survival in the Pyrenees (France). Ecotoxicol. Environ. Saf. 118, 71–82. https://doi.org/10.1016/j.ecoenv.2015.04.003.

BirdLife International, 2017. European birds of conservation concern: Populations , trends and national responsibilities. BirdLife International, Cambridge, UK.

Bounas, A., Sidiropoulos, L., 2024. Aquila chrysaetos. The Greek red list of threatened species. [WWW document]. URL https://redlist.necca.gov.gr/en/assessment/?id=224415705 (accessed 6.8.24).

Bounas, A., Vasilakis, D., Kret, E., Zakkak, S., Chatzinikolaou, Y., Kapsalis, E., Arkumarev, V., Dobrev, D., Stamenov, A., Stoychev, S., Skartsi, T., Sidiropoulos, L., Halley, J.M., 2025. Cumulative collision risk and population-level consequences of industrial wind-power plant development for two vulture species: a quantitative warning. Environ. Impact Assess. Rev. 110, 107669. https://doi.org/10.1016/j.eiar.2024.107669.

Buij, R., Richards, N.L., Rooney, E., Ruddock, M., Horváth, M., Krone, O., Mason, H., Shorrock, G., Chriél, M., Deák, G., Demerdzhiev, D., Deutschová, L., Doktorová, S., Inderwildi, E., Jaspers, V.L.B., Jenny, D., Mikuska, T., Miskovic, M., Mizera, T., Nagy, A., Ntemiri, K., O'Donoghue, B., Ružić, M., Saravia-Mullin, V., Stoychev, S., Tavares, J., Andevski, J., Tulden, P. van, Velevski, M., Vermouzek, Z., Vrezec, A., Zorrilla, I., McClure, C.J.W., 2025. Raptor Poisoning in Europe between 1996 and 2016: A Continental Assessment of the Most Affected Species and the Most Used Poisons 59, jrr2373. https://doi.org/10.3356/jrr2373.

Chapron, G., Kaczensky, P., Linnel, J.D.C., von Arx, M., Huber, D., Andre, H., Lopez-Bao, J.V., Adamec, M., Alvares, F., Anders, O., Balciauskas, L., Balys, V., Bedo, P., Bego, F., Blanco, J.C., Breitenmoser, U., Broseth, H., Iliopoulos, Y., Mertzanis, Y., 2014. Recovery of large carnivores in Europe ' s modern human-dominated landscapes. Science 346, 1517–1519. https://doi.org/10.1126/science.1257553.

Crandall, R.H., Craighead, D.J., Bedrosian, B., Slabe, V.A., 2019. Survival estimates and cause of mortality of Golden eagles in south-Central Montana. J. Raptor Res. 53, 38–45. https://doi.org/10.3356/JRR-18-22.

Crawley, M.J., 2013. The R Book. Wiley, London, UK.

Csermak Jr., A.C., de Araújo, G.R., Pizzutto, C.S., de Deco-Souza, T., Jorge-Neto, P.N., 2023. GPS collars as a tool to uncover environmental crimes in Brazil: the jaguar as a sentinel. Anim. Conserv. 26, 137–139. https://doi.org/10.1111/acv.12826.

Dahl, E.L., May, R., Hoel, P.L., Bevanger, K., Pedersen, H.C., Røskaft, E., Stokke, B.G., 2013. White-tailed eagles (Haliaeetus albicilla) at the Smøla wind-power plant, Central Norway, lack behavioral flight responses to wind turbines. Wildl. Soc. Bull. 37, 66–74. https://doi.org/10.1002/wsb.258.

Demerdzhiev, D., Stoychev, S., Petrov, T., Angelov, I., Nedyalkov, N., 2009. Impact of power lines on bird mortality in southern Bulgaria. Acta Zool. Bulg. 61, 175–183.

Demerdzhiev, D., Stoychev, S., Dobrev, D., Spasov, S., Terziev, N., 2014. Conservation measures undertaken to improve the population status of eastern imperial eagle (Aquila heliaca) in Bulgaria. Slovak Raptor J. 8, 27–39. https://doi.org/10.2478/srj-2014-0007.

Durá-Alemañ, C.J., Almarcha, F., Sánchez-Zapata, J.A., Pérez-Ibarra, I., Morales-Reyes, Z., 2024. Land of wolves, school of shepherds: the importance of pastoral knowledge on co-existence with large carnivores. Ecosyst. People 20, 2422910. https://doi.org/10.1080/26395916.2024.2422910.

EC, 1992. Council Directive 92/43/EEC of 21 May 1992 on the Conservation on Natural Habitats and Wild Fauna and Flora. Belgium, Brussels. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043.

European Commission, 2017. Commission Staff Working Document: Fitness Check of the EU Nature Legislation (Birds and Habitats Directives). European Commission, Brussels, BE.

European Union / Copernicus Land Monitoring Service, 2018. CORINE Land Cover Dataset. European Environment Agency, København, Danmark.

Ferrer, M., Penteriani, V., Balbontín, J., Pandolfi, M., 2003. The proportion of immature breeders as a reliable early warning signal of population decline: evidence from the Spanish imperial eagle in Doñana. Biol. Conserv. 114, 463–466. https://doi.org/10.1016/S0006-3207(03)00085-5.

Fielding, A.H., Haworth, P.F., Anderson, D., Benn, S., Dennis, R., Weston, E., Whitfield, D.P., 2019. A simple topographical model to predict Golden eagle Aquila chrysaetos space use during dispersal. Ibis 162, 400–415. https://doi.org/10.1111/ibi.12718.

Fielding, A.H., Anderson, D., Benn, S., Dennis, R., Geary, M., Weston, E., Whitfield, D.P., 2021. Responses of dispersing GPS-tagged Golden eagles (Aquila chrysaetos) to multiple wind farms across Scotland. Ibis. https://doi.org/10.1111/ibi.12996.

Fielding, A.H., Anderson, D., Benn, S., Reid, R., Tingay, R., Weston, E.D., Whitfield, D.P., 2023. Substantial variation in prospecting behaviour of young Golden eagles Aquila chrysaetos defies expectations from potential predictors. Diversity 15, 506. https://doi.org/10.3390/d15040506.

Fielding, A.H., Anderson, D., Barlow, C., Benn, S., Chandler, C.J., Reid, R., Tingay, R., Weston, E.D., Whitfield, D.P., 2024. The characteristics and variation of the Golden eagle Aquila chrysaetos home range. Diversity 16, 523. https://doi.org/10.3390/d16090523.

Giraldo-Amaya, M., Aguiar-Silva, F.H., Aparicio-U, K.M., Zuluaga, S., 2021. Human persecution of the harpy eagle: a widespread threat? J. Raptor Res. 55, 281–286. https://doi.org/10.3356/0892-1016-55.2.281.

Gotelli, N.J., Ellison, A.M., 2004. A Primer of Ecological Statistics. Sinauer, New York, US.

Government Gazette of the Hellenic Republic, 2023: Law 5037/FEK A78/29.3.2023. Athens, Greece. https://search.et.gr/el/fek/?fekId=593799.

Green, R.E., 2002. Diagnosing causes of population declines and selecting remedial actions. In: Norris, K., Pain, D.J. (Eds.), Conserving Bird Biodiversity General Principles and their Application. Cambridge University Press, Cambridge, UK, pp. 139–156.

Haller, H., 1996. Der Steinadler in Graubunden: Langfristige Untersuchungen zur Populationsokologie von Aquila chrysaetos im Zentrum der Alpen. Ornithol. Beob, Suppl, p. 9.

Hallmann, B., 1985. Status and conservation problems of birds of prey in Greece. In: Chanchellor, R.D. (Ed.), Newton, I. Conservation Studies on Raptors, ICBP, pp. 55–59.

Handrinos, G., Akriotis, T., 1997. The Birds of Greece. Christopher Helm, Lonhdon, UK.

Hernandez-Matias, A., Real, J., Pradel, R., 2011. Quick methods for evaluating survival of age- Characterizable long-lived territorial birds. J. Wildl. Manag. 75, 856–866. https://doi.org/10.1002/jwmg.102.

Hernández-Matías, A., Real, J., Parés, F., Pradel, R., 2015. Electrocution threatens the viability of populations of the endangered Bonelli's eagle (Aquila fasciata) in southern Europe. Biol. Conserv. 191, 110–116. https://doi.org/10.1016/j.biocon.2015.06.028.

Herzon, I., 2022. Golden eagle conservation scheme. [WWW document]. Result based Paym. Newtork Finl. URL https://www.rbpnetwork.eu/country-infos/finland/golden-eagle-conservation-scheme-30/ (accessed 11.3.24).

Hijmans, R.J., 2024. Package "Terra": Spatial Data Analysis.

Hunt, W.G., Wiens, J.D., Law, P.R., Fuller, M.R., Hunt, T.L., Driscoll, D.E., Jackman, R.E., 2017. Quantifying the demographic cost of human related mortality to a raptor population. PLoS One 12, 1–22. https://doi.org/10.1371/journal.pone.0172232.

Iliopoulos, Y., Astaras, C., Lazarou, Y., Petridou, M., Kazantzidis, S., Waltert, M., 2019. Tools for co-existence: Fladry corrals efficiently repel wild wolves (Canis lupus) from experimental baiting sites. Wildl. Res. 46, 484–498. https://doi.org/10.1071/WR18146.

Iliopoulos, Y., Antoniadi, E., Kret, E., Zakkak, S., Skartsi, T., 2021. Wolf–hunting dog interactions in a biodiversity hot spot area in northern Greece: preliminary assessment and implications for conservation in the dadia-lefkimi-soufli forest national park and adjacent areas. Animals 11. https://doi.org/10.3390/ani11113235.

Kanellopoulos, N., Mertzanis, G., Korakis, G., Panagiotopoulou, M., 2006. Selective habitat use by brown bear (Ursus arctos L.) in northern Pindos. Greece. J. Biol. Res. 5, 23–33.

Kati, V., Hovardas, T., Dieterich, M., Ibisch, P.L., Mihok, B., Selva, N., 2015. The challenge of implementing the European network of protected areas Natura 2000. Conserv. Biol. 29, 260–270. https://doi.org/10.1111/cobi.12366.

Kati, V., Kassara, C., Vrontisi, Z., Moustakas, A., 2021. The biodiversity-wind energy-land use nexus in a global biodiversity hotspot. Sci. Total Environ. 768, 144471. https://doi.org/10.1016/j.scitotenv.2020.144471.

Kati, V., Kassara, C., Panagos, P., Tampouratzi, L., Gotsis, D., Tzortzakaki, O., Petridou, M., Psaralexi, M., Sidiropoulos, L., Vasilakis, D., Zakkak, S., Galani, A., Mpoukas, N., 2023. The overlooked threat of land take from wind energy infrastructures: quantification, drivers and policy gaps. J. Environ. Manag. 348, 119340. https://doi.org/10.1016/j.jenvman.2023.119340.

Kitowski, I., Łopucki, R., Stachniuk, A., Fornal, E., 2021. Banned pesticide still poisoning EU raptors. Science 371, 1319–1320. https://doi.org/10.1126/science.abh0840.

Krone, O., 2018. Lead poisoning in birds of prey. In: Sarasola, J.H., Grande, J.M., Negro, J.J. (Eds.), Birds of Prey, Biology and Conservation in the XXI Century, pp. 251–272. Cham, Switzerland.

Laake, J.L., 2022. Package "RMark" v3.0 [WWW Document]. URL. https://cran.r-project.org/web/packages/RMark/.

Lazarova, I., Dobrev, D., Gradev, G., Petrov, R., Stoychev, S., Klisurov, I., Demerdzhiev, D., 2020. Main mortality factors for the eastern Imperial eagle (Aquila heliaca Savigny, 1809) in Bulgaria. Ornis Hung. 28, 120–134. https://doi.org/10.2478/orhu-2020-0021.

López-Peinado, A., Singh, N.J., Urios, V., López-López, P., 2023. Experimental food subsidies keep eagles inside protected areas: implications for conservation and resource management. Biol. Conserv. 286, 110259. https://doi.org/10.1016/j.biocon.2023.110259.

Loss, S.R., Will, T., Marra, P.P., 2015. Direct mortality of birds from anthropogenic causes. Annu. Rev. Ecol. Evol. Syst. 46, 99–120. https://doi.org/10.1146/annurev-ecolsys-112414-054133.

Mancinelli, S., Boitani, L., Ciucci, P., 2018. Determinants of home range size and space use patterns in a protected wolf (Canis lupus) population in the central Apennines. Italy. Can. J. Zool. 96, 828–838. https://doi.org/10.1139/cjz-2017-0210.

Mateo-Tomás, P., Olea, P.P., Sánchez-Barbudo, I.S., Mateo, R., 2012. Alleviating human-wildlife conflicts: identifying the causes and mapping the risk of illegal poisoning of wild fauna. J. Appl. Ecol. 49, 376–385. https://doi.org/10.1111/j.1365-2664.2012.02119.x.

McIntyre, C.L., 2012. Quantifying sources of mortality and wintering ranges of Golden eagles from interior Alaska using banding and satellite tracking. J. Raptor Res. 46, 129–134. https://doi.org/10.3356/JRR-10-96.1.

Müller, K., Altenkamp, R., Brunnberg, L., 2007. Morbidity of free-ranging White-Tailed Sea eagles (Haliaeetus albicilla) in Germany. J. Avian Med. Surg. 21, 265–274. https://doi.org/10.1647/2007-001r.1.

Murgatroyd, M., Bouten, W., Amar, A., 2021. A predictive model for improving placement of wind turbines to minimise collision risk potential for a large soaring raptor. J. Appl. Ecol. 58, 857–868. https://doi.org/10.1111/1365-2664.13799.

Newton, I., 2021. Killing of raptors on grouse moors: evidence and effects. Ibis 163, 1–19. https://doi.org/10.1111/ibi.12886.

Newton, I.A.N., Mcgrady, M.J., Oli, M.K., 2016. A review of survival estimates for raptors and owls. Ibis 158, 227–248. https://doi.org/10.1111/ibi.12355.

Ntemiri, K., Saravia, V., Angelidis, C., Baxevani, K., Probonas, M., Kret, E., Mertzanis, Y., Iliopoulos, Y., Georgiadis, L., Skartsi, D., Vavylis, D., Manolopoulos, A., Michalopoulou, P., Xirouchakis, S.M., 2018. Animal mortality and illegal poison bait use in Greece. Environ. Monit. Assess. 190, 488. https://doi.org/10.1007/s10661-018-6838-5.

Oppel, S., Dobrev, V., Arkumarev, V., Saravia, V., Bounas, A., Kret, E., Skartsi, T., Velevski, M., Stoychev, S., Nikolov, S.C., 2016. Assessing the effectiveness of intensive conservation actions: does guarding and feeding increase productivity and survival of Egyptian vultures in the Balkans? Biol. Conserv. 198, 157–164. https://doi.org/10.1016/j.biocon.2016.04.002.

Pedrini, P., Sergio, F., 2001. Density, productivity, diet and human persecution of Golden eagles (Aquila chrysaetos) in the central-eastern Italian Alps. J. Raptor Res. 35, 40–48.

Penteriani, V., Otalora, F., Sergio, F., Ferrer, M., 2005. Environmental stochasticity in dispersal areas can explain the 'mysterious' disappearance of breeding populations. Proc. R. Soc. B Biol. Sci. 272, 1265–1269. https://doi.org/10.1098/rspb.2005.3075.

Penteriani, V., Otalora, F., Ferrer, M., 2008. Floater mortality within settlement areas can explain the Allee effect in breeding populations. Ecol. Model. 213, 98–104. https://doi.org/10.1016/j.ecolmodel.2007.11.009.

Peshev, H., Mitrevichin, E., Stoyanov, G., Grozdanov, A., Stoynov, E., 2022. GPS tracking data relates vulture mortality due to acute intoxication at a considerable distance from the site of poisoned bait consumption. Forensic Sci. Int. Anim. Environ. 2, 100052. https://doi.org/10.1016/j.fsiae.2022.100052.

Petridou, M., Benson, J.F., Gimenez, O., Iliopoulos, Y., Kati, V., 2023. Do husbandry practices reduce depredation of free-ranging livestock? A case study with wolves in Greece. Biol. Conserv. 283, 110097. https://doi.org/10.1016/j.biocon.2023.110097.

Pollock, K.H., Winterstein, S.R., Bunck, C.M., Curtis, P.D., 1989. Survival analysis in telemetry studies: the staggered entry design. J. Wildl. Manag. 53, 7–15. https://doi.org/10.2307/3801296.

QGIS Development team, 2021. QGIS geographic information system v3.34 [WWW document]. URL http://qgis.osgeo.org (accessed 1.16.24).

R-Core_Team, 2023. R: A Language and Environment for Statistical Computing. v 4.2.3.. R Foundation for Statistical Computing, Vienna, Austria.

Sidiropoulos, L., Whitfield, D.P., Astaras, C., Vasilakis, D., Alivizatos, H., Kati, V., 2022. Pronounced seasonal diet diversity expansion of Golden eagles (Aquila chrysaetos) in northern Greece during the non-breeding season: the role of tortoises. Diversity 14, 135.

Sidiropoulos, L., Whitfield, D.P., Poirazidis, K., Navarrete, E., Vasilakis, D.P., Bounas, A., Kret, E., Kati, V., 2024a. Dispersal ecology of Golden eagles (Aquila chrysaetos) in northern Greece: onset, ranging, Temporary and Territorial Settlement. Diversity 16, 580. https://doi.org/10.3390/d16090580.

Sidiropoulos, L., Xirouchakis, S., Alivizatos, H., Boukas, N., Bounas, A., Bourdakis, E., Christopoulos, A., Damianakis, K., Evangelidis, A., Kret, E., Navarrete, E., Papaioannou, H., Rousopoulos, G., Tsiakiris, R., Tsiopelas, N., Stara, K., Vasilakis, D., 2024b. The Golden eagle in Greece. In: Ellis, D.H., Bautista, J., Ellis, C., H. (Eds.), The Golden Eagle around the World. Hancock House Publishers, Blaine, WA, US and Surrey, BC, Canada, pp. 397–415.

Skartsi, T., Elloriaga, J., Vasilakis, D.P., 2010. Eurasian black vulture: The focal species of the Dadia-Lefkimi-Soufli Forest national park. In: Katsadorakis, G., Thelander, C. (Eds.), WWF Greece. WWF Greece, Athens, GR, pp. 195–206.

Stara, K., Sidiropoulos, L., Tsiakiris, R., 2016. Bound Eagles , Evil Vultures and Cuckoo Horses . Preserving the Bio-Cultural Diversity of Carrion Eating Birds. Hum. Ecol. 44, 751–764. doi:https://doi.org/10.1007/s10745-016-9864-3.

Stojadinović, D.M., Milošević, D.D., Sretić, K.S., Cvetković, M.P., Jovanović, T.R., Jovanović, B.L., Crnobrnja-Isailović, J.M., 2017. Activity patterns and habitat preference of eastern Hermann's tortoise (Testudo hermanni boettgeri) in Serbia. Turk. J. Zool. 41, 1036–1044. https://doi.org/10.3906/zoo-1702-21.

Tikkanen, H., Pakanen, V.-M., Karlin, O.-P., Lamminmäki, J., 2024. Survival estimates of GPS-tagged adult Golden eagles (Aquila chrysaetos) breeding in Finland. Ornis Fenn. 101, 91–100. https://doi.org/10.51812/of.144459.

Valverde, I., Espín, S., Gómez-Ramírez, P., Sánchez-Virosta, P., García-Fernández, A.J., Berny, P., 2022. Developing a European network of analytical laboratories and government institutions to prevent poisoning of raptors. Environ. Monit. Assess. 194, 113. https://doi.org/10.1007/s10661-021-09719-2.

Vasilakis, D.P., Whitfield, D.P., Schindler, S., Poirazidis, K.S., Kati, V., 2016. Reconciling endangered species conservation with wind farm development: cinereous vultures (Aegypius monachus) in South-Eastern Europe. Biol. Conserv. 196, 10–17. https://doi.org/10.1016/j.biocon.2016.01.014.

Vavylis, D., Bounas, A., Karris, G., Triantis, K.A., 2021. The state of breeding birds in Greece: trends, threats, and implications for conservation. Bird Conserv. Int. 31, 495–509. https://doi.org/10.1017/S0959270920000568.

Velevski, M., Nikolov, S.C., Hallmann, B., Dobrev, V., Sidiropoulos, L., Saravia, V., Tsiakiris, R., Arkumarev, V., Galanaki, A., Kominos, T., Stara, K., Kret, E., Grubač, B., Lisičanec, E., Kastritis, T., Vavylis, D., Topi, M., Hoxha, B., Oppel, S., 2015. Population decline and range contraction of the Egyptian vulture Neophron percnopterus in the Balkan Peninsula. Bird Conserv. Int. 25. https://doi.org/10.1017/S0959270914000343.

Watson, J., 2010. The Golden Eagle. Poyser, London, UK.

White, G.C., Burnham, K.P., 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46, S120–S139. https://doi.org/10.1080/00063659909477239.

Whitfield, D.P., Fielding, A.H., 2017. Analyses of the Fates of Satellite Tracked Golden Eagles in Scotland. Scottish Natural Heritage, Inverness, Scotland, UK.

Whitfield, D.P., McLeod, D.R.A., Watson, J., Fielding, A.H., Haworth, P.F., 2003. The association of grouse moor in Scotland with the illegal use of poisons to control predators. Biol. Conserv. 114, 157–163. https://doi.org/10.1016/S0006-3207(03)00019-3.

Whitfield, D.P., Fielding, A.H., Mcleod, D.R.A., Haworth, P.F., 2004. Modelling the effects of persecution on the population dynamics of golden eagles in Scotland. Biol. Conserv. 119, 319–333. https://doi.org/10.1016/j.biocon.2003.11.015.

Whitfield, D.P., Fielding, A.H., McLeod, D.R.A., Haworth, P.F., Watson, J., 2006. A conservation framework for the golden eagle in Scotland: refining condition targets and assessment of constraint influences. Biol. Conserv. 130, 465–480. https://doi.org/10.1016/j.biocon.2006.01.008.

Xirouchakis, S., 2001. The Golden Eagle *Aquila chrysaetos* in Crete . Distribution , population status and conservation problems. Avocetta 25, 275–281.

Xirouchakis, S., 2019. Action Plan for the Three Vulture Species: Bearded Vulture (*Gypaetus barbatus*), Griffon Vulture (*Gyps fulvus*), Cinereous Vulture (*Aegypius monachus*). LIFE-IP 4 NATURA Project: Integrated Actions for the Conservation and Management of Natura 2000 Sites, Species, Habitats and Ecosystems in Greece (LIFE 16 IPE/GR/000002) Deliverable Action a.1. Hellenic Ornithological Society /, BirdLife Greece, Athens, Greece.